Appearance controls interpretation of orientation flows for 3D shape estimation

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Background

The visual system can infer 3D shape from orientation flows arising from both texture and shading patterns. However, these two types of flows provide fundamentally different information about surface structure.[1] Texture flows, when derived from distinct elements, mainly signal first-order features (surface slant), whereas shading flow orientations primarily relate to second-order surface properties (the change in surface slant).

The source of an image's structure is inherently ambiguous, it is therefore crucial for the brain to identify whether flow patterns originate from texture or shading to correctly infer shape from a 2D image. One possible approach would be to use 'surface appearance' (e.g. smooth gradients vs. fine-scale texture) to distinguish texture from shading. However, the structure of the flow fields themselves may indicate whether a given flow is more likely due to first- or second-order shape information. We test these two possibilities in this set of experiments, looking at speeded and free responses.

Stimuli

A series of naturalistic "blobby" objects were generated using low frequency sinusoidal perturbations of spheres. The objects appeared subtly different when textured or shaded and their texture and shading orientation flows differed in a number of regions (see Fig. 1a). Two new objects were generated from the original object's orientation flows for each blob using deformation operators[2]: One object whose shading flow matched the original object's texture flow (Fig. 1b) and another whose texture flow was equivalent to the original's shading flow (Fig. 1c). Surface appearance was also manipulated using either shading (low frequency) or texture (high frequency) environments.

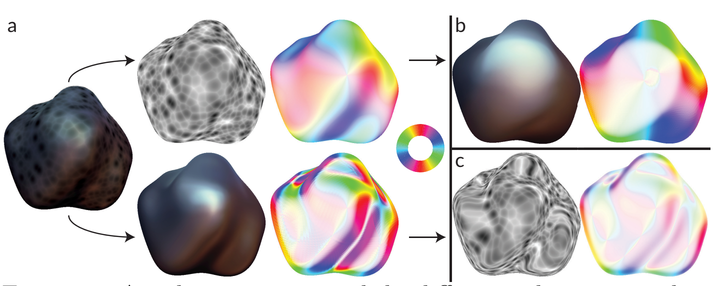

Figure 1: An object appears subtly different when textured or shaded and its orientation flows differ (a)—here, the orientation flows' dominant orientations are coded as hue. In these experiments, the shading and texture flows were used to generate two new objects, one with a shading flow that was equivalent to the original's texture flow (b) and another with a texture flow that matched the original's shading flow (c).

[1] Cholewiak, S. A., Kunsberg, B., Zucker, S., & Fleming, R. W. (2014, May). Predicting 3D shape perception from shading and texture flows. *Visual Sciences Society (VSS) Annual Meeting 2014*. doi: 10.1167/14.10.1113

[2] Vergne, R., Barla, P., Fleming, R., & Granier, X. (2012). Surface Flows for Image-based Shading Design. *ACM Transactions on Graphics*, 31(3), 94:1-94:9. doi: 10.1145/2185520.2185590

Experiment 1 - 2-Alternative Forced Choice

The first experiment used a 2AFC paradigm, where observers were shown two comparisons—one match and one foil—for each blob and indicated which one matched a flashed standard. For textured standards, the foils were the shapes described in Fig. 1b. For shaded standards, the foils were the shapes described in Fig. 1c. Critically, the comparison environment (shading/texture) was also manipulated to change the comparison objects' surface appearance. A subset of the results is illustrated below (Fig. 2).

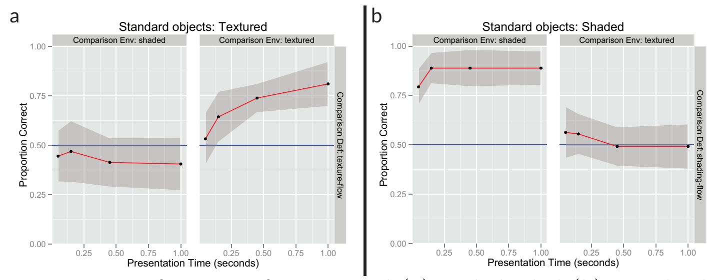

Figure 2: Performance for textured (a) and shaded (b) standards. Blue line is chance. Note performance was higher when the comparison environment matched the standard versus when they differed.

Experiment 2 - Adjustment

In the second experiment, observers matched the perceived shape of a standard object (from Fig. 1a) to a comparison object, which was morphed between the generated shape surfaces. Performance was compared to a model based on orientation flows. A subset of the results is presented below (Fig. 3).

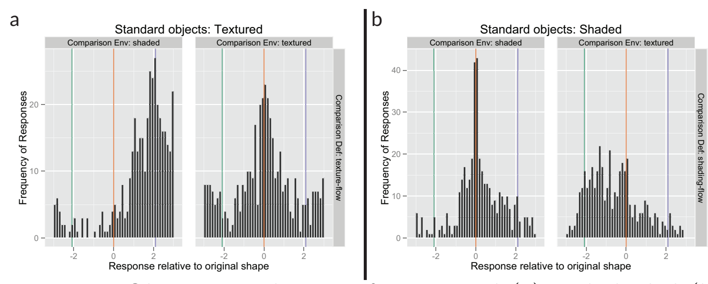

Figure 3: Observers judgments for textured (a) and shaded (b) standard objects. Judgments are relative to the true shape (Fig. 1a) at 0 (orange marker). The shape from Fig. 1b is at $-\frac{2\pi}{3}$ (green marker), while the object from Fig. 1c is at $\frac{2\pi}{3}$ (blue marker). Note the effect of surface appearance, with matches near the base shape when the standard's cue and comparison's environment match.

Conclusion

Both the structure of the flow and the overall appearance are important for shape perception, but appearance cues appear to control the inferred source of the observed flow field and whether the orientation flows in a stimulus are interpreted as texture or shading.

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